

**METHOD AND ARRANGEMENT FOR COMPUTING AND  
REGULATING THE DISTRIBUTION OF A LINEAR LOAD  
IN A MULTI-NIP CALENDER AND A MULTI-NIP CALENDER**

5

**CROSS-REFERENCE TO RELATED APPLICATIONS**

This application is a continuation of U.S. Patent Application Serial No. 09/156,232 filed September 18, 1998 which in turn is a continuation-in-part of U.S. Patent Application Serial No. 09/074,723 filed May 7, 1998, now abandoned, which claims domestic priority of U.S. Provisional Patent Application Serial No. 60/045,871 filed May 7, 1997.

10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65  
66  
67  
68  
69  
70  
71  
72  
73  
74  
75  
76  
77  
78  
79  
80  
81  
82  
83  
84  
85  
86  
87  
88  
89  
90  
91  
92  
93  
94  
95  
96  
97  
98  
99  
100  
101  
102  
103  
104  
105  
106  
107  
108  
109  
110  
111  
112  
113  
114  
115  
116  
117  
118  
119  
120  
121  
122  
123  
124  
125  
126  
127  
128  
129  
130  
131  
132  
133  
134  
135  
136  
137  
138  
139  
140  
141  
142  
143  
144  
145  
146  
147  
148  
149  
150  
151  
152  
153  
154  
155  
156  
157  
158  
159  
160  
161  
162  
163  
164  
165  
166  
167  
168  
169  
170  
171  
172  
173  
174  
175  
176  
177  
178  
179  
180  
181  
182  
183  
184  
185  
186  
187  
188  
189  
190  
191  
192  
193  
194  
195  
196  
197  
198  
199  
200  
201  
202  
203  
204  
205  
206  
207  
208  
209  
210  
211  
212  
213  
214  
215  
216  
217  
218  
219  
220  
221  
222  
223  
224  
225  
226  
227  
228  
229  
230  
231  
232  
233  
234  
235  
236  
237  
238  
239  
240  
241  
242  
243  
244  
245  
246  
247  
248  
249  
250  
251  
252  
253  
254  
255  
256  
257  
258  
259  
260  
261  
262  
263  
264  
265  
266  
267  
268  
269  
270  
271  
272  
273  
274  
275  
276  
277  
278  
279  
280  
281  
282  
283  
284  
285  
286  
287  
288  
289  
290  
291  
292  
293  
294  
295  
296  
297  
298  
299  
300  
301  
302  
303  
304  
305  
306  
307  
308  
309  
310  
311  
312  
313  
314  
315  
316  
317  
318  
319  
320  
321  
322  
323  
324  
325  
326  
327  
328  
329  
330  
331  
332  
333  
334  
335  
336  
337  
338  
339  
340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
350  
351  
352  
353  
354  
355  
356  
357  
358  
359  
360  
361  
362  
363  
364  
365  
366  
367  
368  
369  
370  
371  
372  
373  
374  
375  
376  
377  
378  
379  
380  
381  
382  
383  
384  
385  
386  
387  
388  
389  
390  
391  
392  
393  
394  
395  
396  
397  
398  
399  
400  
401  
402  
403  
404  
405  
406  
407  
408  
409  
410  
411  
412  
413  
414  
415  
416  
417  
418  
419  
420  
421  
422  
423  
424  
425  
426  
427  
428  
429  
430  
431  
432  
433  
434  
435  
436  
437  
438  
439  
440  
441  
442  
443  
444  
445  
446  
447  
448  
449  
450  
451  
452  
453  
454  
455  
456  
457  
458  
459  
460  
461  
462  
463  
464  
465  
466  
467  
468  
469  
470  
471  
472  
473  
474  
475  
476  
477  
478  
479  
480  
481  
482  
483  
484  
485  
486  
487  
488  
489  
490  
491  
492  
493  
494  
495  
496  
497  
498  
499  
500  
501  
502  
503  
504  
505  
506  
507  
508  
509  
510  
511  
512  
513  
514  
515  
516  
517  
518  
519  
520  
521  
522  
523  
524  
525  
526  
527  
528  
529  
530  
531  
532  
533  
534  
535  
536  
537  
538  
539  
540  
541  
542  
543  
544  
545  
546  
547  
548  
549  
550  
551  
552  
553  
554  
555  
556  
557  
558  
559  
560  
561  
562  
563  
564  
565  
566  
567  
568  
569  
570  
571  
572  
573  
574  
575  
576  
577  
578  
579  
580  
581  
582  
583  
584  
585  
586  
587  
588  
589  
590  
591  
592  
593  
594  
595  
596  
597  
598  
599  
600  
601  
602  
603  
604  
605  
606  
607  
608  
609  
610  
611  
612  
613  
614  
615  
616  
617  
618  
619  
620  
621  
622  
623  
624  
625  
626  
627  
628  
629  
630  
631  
632  
633  
634  
635  
636  
637  
638  
639  
640  
641  
642  
643  
644  
645  
646  
647  
648  
649  
650  
651  
652  
653  
654  
655  
656  
657  
658  
659  
660  
661  
662  
663  
664  
665  
666  
667  
668  
669  
670  
671  
672  
673  
674  
675  
676  
677  
678  
679  
680  
681  
682  
683  
684  
685  
686  
687  
688  
689  
690  
691  
692  
693  
694  
695  
696  
697  
698  
699  
700  
701  
702  
703  
704  
705  
706  
707  
708  
709  
710  
711  
712  
713  
714  
715  
716  
717  
718  
719  
720  
721  
722  
723  
724  
725  
726  
727  
728  
729  
730  
731  
732  
733  
734  
735  
736  
737  
738  
739  
740  
741  
742  
743  
744  
745  
746  
747  
748  
749  
750  
751  
752  
753  
754  
755  
756  
757  
758  
759  
760  
761  
762  
763  
764  
765  
766  
767  
768  
769  
770  
771  
772  
773  
774  
775  
776  
777  
778  
779  
780  
781  
782  
783  
784  
785  
786  
787  
788  
789  
790  
791  
792  
793  
794  
795  
796  
797  
798  
799  
800  
801  
802  
803  
804  
805  
806  
807  
808  
809  
810  
811  
812  
813  
814  
815  
816  
817  
818  
819  
820  
821  
822  
823  
824  
825  
826  
827  
828  
829  
830  
831  
832  
833  
834  
835  
836  
837  
838  
839  
840  
841  
842  
843  
844  
845  
846  
847  
848  
849  
850  
851  
852  
853  
854  
855  
856  
857  
858  
859  
860  
861  
862  
863  
864  
865  
866  
867  
868  
869  
870  
871  
872  
873  
874  
875  
876  
877  
878  
879  
880  
881  
882  
883  
884  
885  
886  
887  
888  
889  
890  
891  
892  
893  
894  
895  
896  
897  
898  
899  
900  
901  
902  
903  
904  
905  
906  
907  
908  
909  
910  
911  
912  
913  
914  
915  
916  
917  
918  
919  
920  
921  
922  
923  
924  
925  
926  
927  
928  
929  
930  
931  
932  
933  
934  
935  
936  
937  
938  
939  
940  
941  
942  
943  
944  
945  
946  
947  
948  
949  
950  
951  
952  
953  
954  
955  
956  
957  
958  
959  
960  
961  
962  
963  
964  
965  
966  
967  
968  
969  
970  
971  
972  
973  
974  
975  
976  
977  
978  
979  
980  
981  
982  
983  
984  
985  
986  
987  
988  
989  
990  
991  
992  
993  
994  
995  
996  
997  
998  
999  
1000  
1001  
1002  
1003  
1004  
1005  
1006  
1007  
1008  
1009  
1010  
1011  
1012  
1013  
1014  
1015  
1016  
1017  
1018  
1019  
1020  
1021  
1022  
1023  
1024  
1025  
1026  
1027  
1028  
1029  
1030  
1031  
1032  
1033  
1034  
1035  
1036  
1037  
1038  
1039  
1040  
1041  
1042  
1043  
1044  
1045  
1046  
1047  
1048  
1049  
1050  
1051  
1052  
1053  
1054  
1055  
1056  
1057  
1058  
1059  
1060  
1061  
1062  
1063  
1064  
1065  
1066  
1067  
1068  
1069  
1070  
1071  
1072  
1073  
1074  
1075  
1076  
1077  
1078  
1079  
1080  
1081  
1082  
1083  
1084  
1085  
1086  
1087  
1088  
1089  
1090  
1091  
1092  
1093  
1094  
1095  
1096  
1097  
1098  
1099  
1100  
1101  
1102  
1103  
1104  
1105  
1106  
1107  
1108  
1109  
1110  
1111  
1112  
1113  
1114  
1115  
1116  
1117  
1118  
1119  
1120  
1121  
1122  
1123  
1124  
1125  
1126  
1127  
1128  
1129  
1130  
1131  
1132  
1133  
1134  
1135  
1136  
1137  
1138  
1139  
1140  
1141  
1142  
1143  
1144  
1145  
1146  
1147  
1148  
1149  
1150  
1151  
1152  
1153  
1154  
1155  
1156  
1157  
1158  
1159  
1160  
1161  
1162  
1163  
1164  
1165  
1166  
1167  
1168  
1169  
1170  
1171  
1172  
1173  
1174  
1175  
1176  
1177  
1178  
1179  
1180  
1181  
1182  
1183  
1184  
1185  
1186  
1187  
1188  
1189  
1190  
1191  
1192  
1193  
1194  
1195  
1196  
1197  
1198  
1199  
1200  
1201  
1202  
1203  
1204  
1205  
1206  
1207  
1208  
1209  
1210  
1211  
1212  
1213  
1214  
1215  
1216  
1217  
1218  
1219  
1220  
1221  
1222  
1223  
1224  
1225  
1226  
1227  
1228  
1229  
1230  
1231  
1232  
1233  
1234  
1235  
1236  
1237  
1238  
1239  
1240  
1241  
1242  
1243  
1244  
1245  
1246  
1247  
1248  
1249  
1250  
1251  
1252  
1253  
1254  
1255  
1256  
1257  
1258  
1259  
1260  
1261  
1262  
1263  
1264  
1265  
1266  
1267  
1268  
1269  
1270  
1271  
1272  
1273  
1274  
1275  
1276  
1277  
1278  
1279  
1280  
1281  
1282  
1283  
1284  
1285  
1286  
1287  
1288  
1289  
1290  
1291  
1292  
1293  
1294  
1295  
1296  
1297  
1298  
1299  
1300  
1301  
1302  
1303  
1304  
1305  
1306  
1307  
1308  
1309  
1310  
1311  
1312  
1313  
1314  
1315  
1316  
1317  
1318  
1319  
1320  
1321  
1322  
1323  
1324  
1325  
1326  
1327  
1328  
1329  
1330  
1331  
1332  
1333  
1334  
1335  
1336  
1337  
1338  
1339  
1340  
1341  
1342  
1343  
1344  
1345  
1346  
1347  
1348  
1349  
1350  
1351  
1352  
1353  
1354  
1355  
1356  
1357  
1358  
1359  
1360  
1361  
1362  
1363  
1364  
1365  
1366  
1367  
1368  
1369  
1370  
1371  
1372  
1373  
1374  
1375  
1376  
1377  
1378  
1379  
1380  
1381  
1382  
1383  
1384  
1385  
1386  
1387  
1388  
1389  
1390  
1391  
1392  
1393  
1394  
1395  
1396  
1397  
1398  
1399  
1400  
1401  
1402  
1403  
1404  
1405  
1406  
1407  
1408  
1409  
1410  
1411  
1412  
1413  
1414  
1415  
1416  
1417  
1418  
1419  
1420  
1421  
1422  
1423  
1424  
1425  
1426  
1427  
1428  
1429  
1430  
1431  
1432  
1433  
1434  
1435  
1436  
1437  
1438  
1439  
1440  
1441  
1442  
1443  
1444  
1445  
1446  
1447  
1448  
1449  
1450  
1451  
1452  
1453  
1454  
1455  
1456  
1457  
1458  
1459  
1460  
1461  
1462  
1463  
1464  
1465  
1466  
1467  
1468  
1469  
1470  
1471  
1472  
1473  
1474  
1475  
1476  
1477  
1478  
1479  
1480  
1481  
1482  
1483  
1484  
1485  
1486  
1487  
1488  
1489  
1490  
1491  
1492  
1493  
1494  
1495  
1496  
1497  
1498  
1499  
1500  
1501  
1502  
1503  
1504  
1505  
1506  
1507  
1508  
1509  
1510  
1511  
1512  
1513  
1514  
1515  
1516  
1517  
1518  
1519  
1520  
1521  
1522  
1523  
1524  
1525  
1526  
1527  
1528  
1529  
1530  
1531  
1532  
1533  
1534  
1535  
1536  
1537  
1538  
1539  
1540  
1541  
1542  
1543  
1544  
1545  
1546  
1547  
1548  
1549  
1550  
1551  
1552  
1553  
1554  
1555  
1556  
1557  
1558  
1559  
1560  
1561  
1562  
1563  
1564  
1565  
1566  
1567  
1568  
1569  
1570  
1571  
1572  
1573  
1574  
1575  
1576  
1577  
1578  
1579  
1580  
1581  
1582  
1583  
1584  
1585  
1586  
1587  
1588  
1589  
1590  
1591  
1592  
1593  
1594  
1595  
1596  
1597  
1598  
1599  
1600  
1601  
1602  
1603  
1604  
1605  
1606  
1607  
1608  
1609  
1610  
1611  
1612  
1613  
1614  
1615  
1616  
1617  
1618  
1619  
1620  
1621  
1622  
1623  
1624  
1625  
1626  
1627  
1628  
1629  
1630  
1631  
1632  
1633  
1634  
1635  
1636  
1637  
1638  
1639  
1640  
1641  
1642  
1643  
1644  
1645  
1646  
1647  
1648  
1649  
1650  
1651  
1652  
1653  
1654  
1655  
1656  
1657  
1658  
1659  
1660  
1661  
1662  
1663  
1664  
1665  
1666  
1667  
1668  
1669  
1670  
1671  
1672  
1673  
1674  
1675  
1676  
1677  
1678  
1679  
1680  
1681  
1682  
1683  
1684  
1685  
1686  
1687  
1688  
1689  
1690  
1691  
1692  
1693  
1694  
1695  
1696  
1697  
1698  
1699  
1700  
1701  
1702  
1703  
1704  
1705  
1706  
1707  
1708  
1709  
1710  
1711  
1712  
1713  
1714  
1715  
1716  
1717  
1718  
1719  
1720  
1721  
1722  
1723  
1724  
1725  
1726  
1727  
1728  
1729  
1730  
1731  
1732  
1733  
1734  
1735  
1736  
1737  
1738  
1739  
1740  
1741  
1742  
1743  
1744  
1745  
1746  
1747  
1748  
1749  
1750  
1751  
1752  
1753  
1754  
1755  
1756  
1757  
1758  
1759  
1760  
1761  
1762  
1763  
1764  
1765  
1766  
1767  
1768  
1769  
1770  
1771  
1772  
1773  
1774  
1775  
1776  
1777  
1778  
1779  
1780  
1781  
1782  
1783  
1784  
1785  
1786  
1787  
1788  
1789  
1790  
1791  
1792  
1793  
1794  
1795  
1796  
1797  
1798  
1799  
1800  
1801  
1802  
1803  
1804  
1805  
1806  
1807  
1808  
1809  
1810  
1811  
1812  
1813  
1814  
1815  
1816  
1817  
1818  
1819  
1820  
1821  
1822  
1823  
1824  
1825  
1826  
1827  
1828  
1829  
1830  
1831  
1832  
1833  
1834  
1835  
1836  
1837  
1838  
1839  
1840  
1841  
1842  
1843  
1844  
1845  
1846  
1847  
1848  
1849  
1850  
1851  
1852  
1853  
1854  
1855  
1856  
1857  
1858  
1859  
1860  
1861  
1862  
1863  
1864  
1865  
1866  
1867  
1868  
1869  
1870  
1871  
1872  
1873  
1874  
1875  
1876  
1877  
1878  
1879  
1880  
1881  
1882  
1883  
1884  
1885  
1886  
1887  
1888  
1889  
1890  
1891  
1892  
1893  
1894  
1895  
1896  
1897  
1898  
1899  
1900  
1901  
1902  
1903  
1904  
1905  
1906  
1907  
1908  
1909  
1910  
1911  
1912  
1913  
1914  
1915  
1916  
1917  
1918  
1919  
1920  
1921  
1922  
1923  
1924  
1925  
1926  
1927  
1928  
1929  
1930  
1931  
1932  
1933  
1934  
1935  
1936  
1937  
1938  
1939  
1940  
1941  
1942  
1943  
1944  
1945  
1946  
1947  
1948  
1949  
1950  
1951  
1952  
1953  
1954  
1955  
1956  
1957  
1958  
1959  
1960  
1961  
1962  
1963  
1964  
1965  
1966  
1967  
1968  
1969  
1970  
1971  
1972  
1973  
1974  
1975  
1976  
1977  
1978  
1979  
1980  
1981  
1982  
1983  
1984  
1985  
1986  
1987  
1988  
1989  
1990  
1991  
1992  
1993  
1994  
1995  
1996  
1997  
1998  
1999  
2000  
2001  
2002  
2003  
2004  
2005  
2006  
2007  
2008  
2009  
2010  
2011  
2012  
2013  
2014  
2015  
2016  
2017  
2018  
2019  
2020  
2021  
2022  
2023  
2024  
2025  
2026  
2027  
2028  
2029  
2030  
2031  
2032  
2033  
2034  
2035  
2036  
2037  
2038  
2039  
2040  
2041  
2042  
2043  
2044  
2045  
2046  
2047  
2048  
2049  
2050  
2051  
2052  
2053  
2054  
2055  
2056  
2057  
2058  
2059  
2060  
2061  
2062  
2063  
2064  
2065  
2066  
2067  
2068  
2069  
2070  
2071  
2072  
2073  
2074  
2075  
2076  
2077  
2078  
2079  
2080  
2081  
2082  
2083  
2084  
2085  
2086  
2087  
2088  
2089  
2090  
2091  
2092  
2093  
2094  
2095  
2096  
2097  
2098  
2099  
2100  
2101  
2102  
2103  
2104  
2105  
2106  
2107  
2108  
2109  
2110  
2111  
2112  
2113  
2114  
2115  
2116  
2117  
2118  
2119  
2120  
2121  
2122  
2123  
2124  
2125  
2126  
2127  
2128  
2129  
2130  
2131  
2132  
2133  
2134  
2135  
2136  
2137  
2138  
2139  
2140  
2141  
2142  
2143  
2144  
2145  
2146  
2147  
2148  
2149  
2150  
2151  
2152  
2153  
2154  
2155  
2156  
2157  
2158  
2159  
2160  
2161  
2162  
2163  
2164  
2165  
2166  
2167  
2168  
2169  
2170  
2171  
2172  
2173  
2174  
2175  
2176  
2177  
2178  
2179  
2180  
2181  
2182  
2183  
2184  
2185  
2186  
2187  
2188  
2189  
2190  
2191  
2192

lower roll as well as one or more intermediate rolls interposed between the upper roll and the lower roll. The means of suspension of the intermediate rolls are provided with support cylinders, and all the rolls in the set of rolls are preferably supported so that, when the nips are closed, the bending lines of the rolls are curved downwards.

5 Further, the present invention relates to a multi-nip calender for carrying out the method in accordance with the invention.

### **BACKGROUND OF THE INVENTION**

10 In conventional supercalenders or multi-nip calenders, when the nips are closed, the set of rolls is supported from outside the zone of treatment of the web by means of forces which are substantially equal to what is called the pin load applied to the bearing housings of the rolls during running, or which forces are lower than the pin load. The pin load is commonly defined so that it includes the weight of all of the auxiliary equipment connected with the bearing housings of the roll, such as gap shields, doctors, and so-called take-out leading rolls, and also the weight of the portion placed outside the web width and the weight of the bearing system. This prior art  
15 has been described best in the paper by Rolf van Haag: "Der Weg zum Load Control-System"; Das Papier, 1990, Heft 7, in which the regulation of the linear load in a conventional supercalender is described. In such supercalenders, the rolls are positioned one above the other so that their middle portions are curved upwards or, in a very rare and special case, are fully straight.  
20 The intermediate rolls do not bend in the same way, as compared with one another. Owing to the mode of running, the nip loads in the set of calender rolls are such that the roll masses occurring in the area of the web to be calendered always act with full effect upon all the nip loads placed

underneath the roll concerned. In such a mode of running, it is assumed that the set of rolls is curved in such a way during running that the rigidities of the rolls do not have a substantial effect on the uniformity of the linear loads, and attempts are made to operate the calender based on this assumption so that exclusively the linear loads of the upper roll and of the lower roll are regulated on the basis of measurements of quality.

In Finnish Patent No. 96,334, corresponding to U.S. Pat. No. 5,438,920 (incorporated by reference herein), a calendering method and a calender that applies the method are described, which calender comprises a variable-crown upper roll, a variable-crown lower roll and a number of intermediate rolls placed between the upper roll and the lower roll in nip contact with each other. The rolls are arranged as a substantially vertical stack of rolls on the frame of the calender. A material web to be calendered is passed through the nips formed by the adjacent rolls. The nip load produced by the mass of the rolls in the stack of rolls is eliminated in a specific manner so that all the nips in the calender may be loaded with the desired load, which load is, in a preferred alternative embodiment, equally high in all nips. Thus, the calendering potential could be utilized substantially better than in the earlier calenders. In FI 96,334, it is one of the basic ideas of the prior art calender that rolls bending in the same way are employed in the calender. The conduct of such substantially equally bending rolls in the calender and the simple possibility, permitted by such rolls, of relieving the entire mass of the roll are described, in which case this prior art calender and calendering method differ essentially from the first-mentioned German prior art in the very respect that the effect of the masses of the rolls on the linear loads in the lower nips can be regulated freely.

The prior art described above involves an essential problem. If it is assumed that the

10  
20  
30  
40  
50  
60  
70  
80  
90  
100  
110  
120  
130  
140  
150  
160  
170  
180  
190  
200  
210  
220  
230  
240  
250  
260  
270  
280  
290  
300  
310  
320  
330  
340  
350  
360  
370  
380  
390  
400  
410  
420  
430  
440  
450  
460  
470  
480  
490  
500  
510  
520  
530  
540  
550  
560  
570  
580  
590  
600  
610  
620  
630  
640  
650  
660  
670  
680  
690  
700  
710  
720  
730  
740  
750  
760  
770  
780  
790  
800  
810  
820  
830  
840  
850  
860  
870  
880  
890  
900  
910  
920  
930  
940  
950  
960  
970  
980  
990  
1000

natural deflections of the intermediate rolls in the calender without linear loads, i.e., when the nips are open, and the rigidities of the rolls as well as the masses are different, first it is to be stated that such rolls do not comply with those described in FI 96,334 or U.S. Pat. No 5,438,920, in which all of the intermediate rolls had substantially equal deflections. In reality, the manufacture of such rolls, which substantially meet the absolute requirement stated in these publications without separate operations, is very difficult and also expensive, in which connection it has been ascertained that an entirely trivial algorithm of regulation of linear loads, which does not take into account minor differences between the rolls, is not adequate from the point of view of reliable operation of the calender.

### **OBJECTS AND SUMMARY OF THE INVENTION**

Accordingly, it is an object of the present invention to provide a solution for the problems related to the prior art calenders by developing a novel mode of thinking, which takes into account the properties of deflection of the rolls.

Another object is to provide an improvement over the calender concept described in Finnish Patent No. 96,334 and U.S. Pat. No. 5,438,920, in particular in respect of the manner in which the distribution of linear load can be brought under control in the desired way.

In view of achieving these objects and others, in the method in accordance with the invention, in order to compute and regulate the linear loads, one or more of the physical properties affecting the bending of each intermediate roll under load, such as bending rigidity, mass, shape, and material properties, are taken into account, and the ratio of the linear loads applied to the intermediate rolls, the weight of the rolls, and/or the support forces applied to the

rolls are regulated so that the set of rolls is in a state of equilibrium and a predetermined state of deflection. Preferably, all of the above-noted physical properties are determined and taken into account and the ratio of linear loads, weight of the rolls and support forces are all regulated.

5 The arrangement in accordance with the invention includes an automation system and a computing unit arranged to compute and regulate linear loads taking into account the physical properties affecting the bending of each intermediate roll under load, such as bending rigidity, mass, shape, and material properties, and serving to regulate the ratio of the linear loads applied to the intermediate rolls, the weight of the rolls, and the support forces applied to the rolls so that the set of rolls is in a state of equilibrium and in a predetermined state of deflection.

10 The method in accordance with the invention takes into account the properties of rolls of all types, and thus, in some embodiments of the invention, intermediate rolls are employed in the set of rolls in the calender whose bending properties are different from roll to roll.

15 In the computing or computation in accordance with the method and the arrangement of the invention, the set of rolls can be treated as a single unit. On the other hand, the computing can also be carried out individually in respect of each pair of rolls.

The intermediate rolls in the set of rolls are freely moving, so that just forces are applied to the rolls, but the rolls are not held in position.

20 By means of the method and the arrangement in accordance with the invention and by means of the calender intended for carrying out the method, significant advantages are obtained in particular in the respect that, by means of the arrangement in accordance with the invention, the linear loads in each nip can be regulated to the desired level. The arrangement takes into account and computes the deflection lines of the intermediate rolls and the loads of the relief

5 cylinders corresponding to these deflection lines. The rigidities of the intermediate rolls and the differences in the natural deflections of the rolls arising from differences in mass can be readily compensated for in the arrangement by regulating the support forces of the roll support cylinders. Thus, when an arrangement in accordance with the present invention is employed, the deflection lines of all of the intermediate rolls do not have to be identical. The method and the arrangement of the invention can be applied both with a traditional mode of running of a multi-nip calender, in which the paper web runs through all nips, and to a modified mode of running, in which the paper web is passed through certain, desired nips only.

10 Further advantages and characteristic features of the invention will come out better from the following detailed description of the invention.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

15 Additional objects of the invention will be apparent from the following description of the preferred embodiment thereof taken in conjunction with the accompanying non-limiting drawings, in which:

FIG. 1 is a general illustration of the arrangement in accordance with the invention which is applied in a multi-nip calender for computing and regulating the distribution of linear load;

20 FIGS. 2A, 2B and 2C are exemplifying illustrations of the regulation of the distribution of linear load in the machine direction that can be achieved by means of the arrangement and method in accordance with the invention;

FIGS. 3A, 3B and 3C illustrate the effects of different calendering parameters on the surface properties of paper;

FIG. 4 is a schematic illustration of the relative arrangement of the data bases included in the automation arrangement in accordance with the invention;

FIG. 5 is a schematic illustration of a four-roll calender that carries into effect the method in accordance with the invention;

5 FIG. 6 is a schematic illustration of an alternative mode of loading in a multi-roll calender in which the set of rolls in the calender is treated by pairs of rolls;

FIGS. 7A, 7B and 7C are schematic side views illustrating alternative embodiments of the set of rolls in a multi-roll calender in which a mode of loading described in relation to FIG. 6 is employed; and

10 FIG. 8 shows a schematic block diagram that illustrates a model of computing in the arrangement in accordance with the invention.

### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

15 Referring to FIGS. 1-8 wherein like reference numerals refer to the same or similar elements, FIG. 1 is a general view of the arrangement in accordance with the invention in which a calender is denoted generally by reference numeral 10, an automation system is denoted by reference numeral 30, and a computing unit included in the automation system 30 is denoted by reference numeral 40. The calender 10 shown in FIG. 1 has a construction similar to that described, e.g., in Finnish Patent No. 96,334, and thus, the calender 10 comprises a calender  
20 frame 11 on which the set of rolls 12 consisting of a number of rolls has been installed substantially in the vertical plane. The set of rolls 12 comprises an upper roll 13, a lower roll 14, and a number of intermediate rolls 15-22 situated between the upper roll 13 and the lower roll 14

one above the other, which rolls are, in the embodiment illustrated in FIG. 1, in nip contact with each other. A paper, board or other material web W is passed over alignment, spreader and take-out leading rolls into the upper nip  $N_1$  and further through the other nips  $N_2, \dots, N_8$  in the calender and finally out through the lower nip  $N_9$ . As shown in FIG. 1, the paper web W is taken, in the  
5 gaps between the nips  $N_1, \dots, N_9$ , apart from the faces of the calender rolls by means of take-out leading rolls.

The upper roll 13 in the calender is a variable-crown roll, for example a roll adjustable in zones, having a bearing housing 131 attached directly to the calender frame 11. The axle of the variable-crown upper roll 13 is mounted in the bearing housing 131 and, in a conventional  
10 manner, the roll is provided with inside, inner or interior loading means, for example zone cylinders, by whose means the deflection of the roll mantle can be regulated in a desired way.

In a similar manner, the lower roll 14 in the calender is a variable-crown roll, in particular a roll adjustable in zones, having a mantle mounted to rotate about the roll axle and which roll 14 is provided with inner loading means, for example zone cylinders, by whose means the deflection  
15 of the roll mantle can be regulated in a desired way. The axle of the lower roll 14 is mounted in bearing housings 141, which have been mounted as shown in FIG. 1, on loading arms 142.

Loading arms 142 are attached to the calender frame 11 pivotally by means of articulated joints 143. Between the calender frame 11 and the loading arms 142, lower cylinders 144 are mounted, by whose means the lower roll 14 can be shifted in the vertical plane. Thus, the set of rolls 12 can  
20 be loaded by means of the lower cylinders 144, and further, by means of the lower cylinders 144, if necessary, it is possible to open the set of rolls 12. By means of the zone cylinders of the variable-crown upper and lower rolls 13, 14, in the method and the arrangement in accordance



with the invention, a necessary correction and/or desired regulation of the cross-direction profile of the paper web W can be carried out.

Between the upper and the lower rolls 13,14 in the calender, a number of intermediate rolls 15-22, which are in nip contact with each other, are arranged as stated above. In the following, exclusively the uppermost intermediate roll 15 will be examined, and the related constructions are described in more detail with the aid of reference numerals. A corresponding description can also be applied to the other constructions of intermediate rolls in the calender. The intermediate roll 15 is mounted from its ends to revolve in bearing housings 151. Bearing housings 151 are mounted on lever arms 152, which in turn, are pivotally mounted on the calender frame 11 by means of articulated joints 153 arranged in the axial direction of the roll 15. The lever arms 152 are provided with support means 154, which are preferably hydraulic cylinders. Cylinders 154 are elongate and are attached at one end to the lever arms 152 and at an opposite end to the calender frame 11.

By means of the cylinders 154, a support force is applied to the support constructions of the roll 15 and by means of which force, the loads caused by the weights of the roll 15 and related auxiliary equipment, such as the takeout leading roll 155 (however, always at least the weight of the auxiliary equipment connected with the roll as added with the weight of the parts placed outside the web), can be compensated for and supported in the desired and/or necessary manner. The support can also be carried out so that the loads are supported completely, in which case the weights of the roll 15 and the connected auxiliary equipment have no effect on the nip load, i.e., do not increase the nip load. If such complete support is carried into effect in respect of all of the intermediate rolls 15-22, the linear load in each nip  $N_1, \dots, N_9$  can be made

substantially equally high.

FIG. 2A is a schematic illustration of the situation of loading in the set of rolls, in which connection each nip  $N_1, \dots, N_9$  has an equally high linear load. In this connection, a new term is also introduced in calendering technique, i.e., the loading angle  $\alpha$ , because this novel mode of loading cannot be illustrated unequivocally in traditional ways. The loading angle  $\alpha$  illustrates the distribution of linear load in the set of rolls from nip to nip, and in the case of FIG. 2A, i.e., in a case of complete relief, the loading angle  $\alpha = 90^\circ$ . By means of the loading angle  $\alpha$  being about  $90^\circ$ , compared with conventional calenders, a significant increase in the calendering potential is obtained. This increase in calendering potential can be utilized in order to increase the running speed of the web through the calender and the productivity of the calender.

The magnitude of the linear load can be regulated fully freely in order to achieve the desired calendering effect, and, in particular in the case of "full relief", i.e., with a loading angle  $\alpha$  of about  $90^\circ$ , the calendering effect can be regulated in the way illustrated in FIG. 2A by way of example. A high linear load and a high calendering effect  $\underline{a}$  are employed in order to maximize the running speed of the calender, the productivity, and the paper quality. A low linear load and a low calendering effect  $\underline{a}'$  are needed under different conditions and in different production stages, such as in matt calendering, in optimizing of quality, in stages of starting up and running down, and in situations of web break. By means of  $\underline{a}$ , the solution in accordance with the present invention, a very low calendering effect can be achieved in each nip in the calender, as illustrated in FIG. 2A by way of example.

FIG. 2B illustrates a situation in which, in comparison to a calender with a conventional mode of loading in which the loading angle  $\alpha$  is, e.g., about  $54^\circ$ , in a mode of running in

accordance with the present invention, a loading angle  $\alpha = 90^\circ$  is employed. As indicated clearly by FIG. 2B, with a mode of running in accordance with the present invention, a significantly lower level of linear load is needed to produce similar properties of quality of paper, i.e., paper having the same properties. However, in accordance with the principles of the invention, it is possible, for example, to minimize the strain applied to the soft-faced rolls in the calender, such as polymer-coated rolls, in particular in the lower part of the set of rolls.

The loads produced by the mass of the intermediate rolls 15-22 in the set of rolls 12 and by the mass of the auxiliary devices connected with these rolls can, if necessary, also be relieved partially, or so that exclusively the pin loads are relieved, in which case, in respect of the distribution of linear load in the set of rolls, for example, a situation as shown in FIG. 2C is reached. As shown in FIG. 2C, the loading angle  $\alpha$  can be adjusted, e.g., in a range from about  $75^\circ$  to about  $80^\circ$ . As a result, the linear loads are always increasing in the nips when moving towards a lower nip.

In conventional and traditional supercalenders, the loading angle has generally been in the range of from about  $45^\circ$  to about  $55^\circ$ , and the magnitude of this loading angle has been dependent on the size of the calender, i.e., mainly on the number of rolls. In the method in accordance with the present invention, the magnitude of the loading angle  $\alpha$  can be adjusted quite freely, and by means of this adjustability of the loading angle, a considerable advantage and a remarkable improvement are achieved over earlier calendering constructions. The loading angle  $\alpha$  can be used as an active variable in fine adjustment of the differences between different faces of the paper. Adjustment of two-sidedness has a significant effect on the properties of quality of paper, and in this manner, by means of the present invention, it is possible to produce paper of

uniform quality reel after reel. A corresponding property has not been suggested anywhere else previously.

The support can, of course, also be accomplished, for example, as a what is called "excessive relief", wherein the loading angle  $\alpha$  is larger than  $90^\circ$ . In such a case, it is possible to reach a situation in which a lower nip always has a lower linear load than the nip placed above has. Such an embodiment has, however, not been illustrated herein.

In order to establish the significance of the loading angle  $\alpha$  and its adjustability in comparison with other calendering parameters or variables, an extensive test program has been carried out with a test machine, and an example of the test results is given in FIGS. 3A, 3B and 3C, which illustrate the effects of different calendering parameters with different paper grades. In FIG. 3A, the paper grade is SC paper, in FIG. 3B, the grade is LWC paper, and in FIG. 3C, the grade is WFC paper. The effects of different factors on the surface properties of paper (gloss, roughness/smoothness) were determined by means of the results, which were obtained by changing the calendering parameters to a certain extent. The variables that were used were running speed, linear load, temperature, and loading angle, as follows:

Speed:	change in speed about 200 meters per minute
Linear load:	change in load about 50 kN/m
Temperature:	change in surface temperature of heated roll about $15^\circ\text{C}$
Loading angle:	change in loading angle from about $50^\circ$ to about $90^\circ$ ( $50^\circ$ represents the loading with a traditional mode of supercalendering, and $90^\circ$ represents an angle which can be obtained with the

method in accordance with the present invention)

As seen clearly from FIGS. 3A, 3B and 3C, the effect of a change in loading angle on improvement of the surface properties of paper is higher than with any other calendering parameter.

FIG. 1, and also FIGS. 2A, 2B and 2C, illustrate an embodiment in which the set of rolls 12 consisting of the rolls has been installed substantially vertically. The solution is, of course, not confined to such an embodiment only, but the set of rolls can be placed in an obliquely vertical position at least to some extent diverging from the straight, vertical position. Of the rolls included in the set of rolls 12, one or several may be soft-coated polymer rolls and/or paper rolls, fiber rolls or other soft-faced rolls. In the exemplifying embodiment shown in FIG. 1, the upper and lower rolls 13,14 are provided with a soft polymer coating, the first, third, sixth, and eighth intermediate rolls 15,17,20, and 22 are hard-faced chilled rolls, and the second, fourth, fifth, and seventh intermediate rolls 16,18,19,21 are soft-coated polymer rolls. The number of the intermediate rolls or the relative sequence and arrangement of the soft-faced/hard rolls is, however, in no way confined to the exemplifying embodiment of FIG. 1.

In the method in accordance with the present invention, a situation corresponding to a normal production situation is examined, in which case the set of rolls 12 is closed in the way shown in FIG. 1 and the rolls 13-22 are under load in contact with one another. As shown in FIG. 1, the automation system 30 included in the arrangement in accordance with the invention is connected to the support cylinders 154 to measure and control the loads of the relief cylinders. In the method to be examined, in the nips  $N_1, \dots, N_9$  in the set of rolls 12, in the running direction of

the paper web W, a uniform or different, desired distribution of linear load is formed so that in the automation system 30 the deflection lines of the intermediate rolls 15-22 and the corresponding loads of the cylinders 154 of support of the intermediate rolls are computed. The support cylinders 154 and the lever arms 152 are used for supporting the mass of the intermediate rolls 15-22 and the masses of the auxiliary devices connected with the intermediate rolls.

As was already stated with reference to FIGS. 2A, 2B and 2C, the distribution of linear load in the machine direction is regulated by supporting the mass of the rolls and the connected auxiliary devices completely. Thus, besides the mass of the intermediate rolls, by means of the support cylinders 154 and the lever arms 152, the mass of the auxiliary devices connected with the lever arms of each intermediate roll, such as take-out leading rolls, possible doctors, etc., are also supported. The rigidities and mass of the intermediate rolls 15-22 are not equal from roll to roll. Correction of the errors in the cross-direction profiles of the deflection lines of the rolls, arising from these differences in rigidity and mass, i.e., regulation of the deflection lines of the intermediate rolls, is carried out by correcting the loads of the support cylinders of the intermediate rolls from their nominal value by means of the necessary term corresponding to the difference in pressure. The regulation of the deflection lines of the variable-crown upper roll and lower roll 13, 14 is carried out in a conventional manner by means of the zone cylinders in the rolls. When the deflection lines of the variable-crown upper and lower roll 13, 14 are regulated so that they are equal to the deflection lines of the intermediate rolls 15-22, it is possible to give the set of rolls 12 the desired level of linear load in the machine direction by hydraulically loading either the upper roll or the lower roll. In the case of FIG. 1, this loading can be arranged by means of the lower roll 14, because the loading cylinders 144 have been connected to act upon

the lower roll.

In the method and the arrangement in accordance with the invention, the necessary correction and regulation of the cross-direction profile of paper, e.g., of thickness and/or glaze, is carried out by means of the zone cylinders in the variable-crown upper and lower roll 13,14. In the intermediate nips, i.e., in the nips  $N_2, \dots, N_8$  between the intermediate rolls 15-22, correction of the cross-direction profile can be carried out by means of regulation of the loading of the relief cylinders of the intermediate rolls. The method in accordance with the invention and the related computing of the distribution of the linear load in the set of rolls 12 can be applied both to a traditional mode of running of a multi-nip calender, wherein the paper web W runs through all of the nips  $N_1, \dots, N_9$ , and to a modified mode of running, wherein the paper web W is passed through certain nips only. In the method in accordance with the invention, the automation system includes programs for maintenance of the set of rolls, distributions of linear load, roll parameters, and recipe data bases which, together with the program for computing the distribution of linear load, permit computing of the distributions of linear load specifically for each paper grade. Further, for maintaining the changes in the set of rolls in the calender and for monitoring the stock of rolls, there are program routines of their own.

The distribution of linear load in the set of rolls 12 and the support forces to be passed to the support cylinders of the intermediate rolls 15-22 are computed either in the automation system 30 or in a separate computing unit directly connected with the automation system. The computing model determines the rigidity and the mass distribution of the set of rolls 12 in the calender 10 consisting of chilled rolls and polymer rolls as well as the rigidity of the nips  $N_1, \dots, N_9$  between the rolls. Further, in the computing, the locations and masses of the outside masses

connected with the set of rolls are determined, the effect of temperature on the modulus of elasticity is taken into account, the effect of the roll diameters on the original modulus of elasticity is taken into account, a possible additional linear load of the rolls and the separate effects of the centers of mass and gravity of the roll ends at the tending side and at the driving side are taken into account. The data employed in computing are divided into general calender-specific, nip-specific, and roll-specific data. Thus, the starting-value data necessary for the computing are defined in a roll data base 51, in a roll material data base 52, in a set-of-rolls mass data base 53, in a data base of geometry of the articulated linkage in the calender, i.e., in the set-of-rolls data base 54, as illustrated schematically in FIG. 4. In the computing model applied in the invention, the computing is preferably carried out in two stages so that in the first stage, the support pressures of the intermediate rolls are optimized and correction coefficients are obtained for the variable-crown upper and lower rolls. This data is utilized in the second stage of computing for optimizing the distribution of linear load of the upper roll and the lower roll.

The way in which the calender in accordance with the invention can be made to operate in the desired way, i.e., in which the forces that support the intermediate rolls are determined, is derived from the procedure in accordance with the invention, by whose means the ratio of the linear loads applied to the intermediate rolls, the weight of such rolls, and the support forces applied to such rolls is adjusted to such a level that a pre-determined state of deflection prevails in the area of the set of rolls. In the determination of the deflection of each roll, it is also possible to include a possible mode of grinding of the roll concerned, or the roll in nip contact with the same, to a shape different from the traditional cylindrical shape, such as a positive or negative crown.



When the basic load and the correction of linear load produced by means of the variable-crown rolls operating as end rolls are taken into account in the solution of the equations of deflection of the intermediate rolls, in every case it is possible to achieve such a state of equilibrium for the set of rolls that the distributions of linear load in the nips in the set of rolls correspond to the desired distribution of linear load.

The group of equations that has been formed and that illustrates the conduct of the set of rolls can be solved convergently by means of commonly used numeric solution algorithms of groups of equations. An example of this is FIG. 5, which illustrates a four-roll supercalender, in which the set of rolls 100 comprises a variable-crown lower roll 111, a variable-crown upper roll 112, and two intermediate rolls 113, 114. The nip load in the nips  $N_{101}$ ,  $N_{102}$ ,  $N_{103}$  between the rolls is produced substantially as the spring force required to produce an elastic compression of the coating on one of the rolls that form a nip. Since, at each point, the force is proportional to the difference between the transitions arising in the rolls at the nip, it can be concluded directly that at each point the same load is achieved when the difference in transition at the points is the same, i.e., when the deflection lines of the rolls are of equal shape and equal magnitude. Thus, the optimal relief or support of each roll is determined so that the bending load that remains on each roll mantle produces an equally high deflection on all rolls.

Since normally, the deflection forms of rolls are equal (paraboloidal), in the examination referring to FIG. 5 the deflection of the roll will be described exclusively by means of the deflection of the center point of the roll.

The deflection of a roll as a result of a deflecting linear load produced on the roll mantle can be expressed by means of the formula:

$$\delta_t = k \cdot (q_{ts} / (E_t \cdot l_t))$$

from which the load is obtained by means of the deflection:

$$q_{ts} = ((E_t \cdot l_t) / k) \cdot \delta_t$$

5

wherein:

$\delta_t$  = deflection of roll;

$k$  = coefficient depending on mode of loading;

$q_{ts}$  = linear load that deflects the roll;

$E_t$  = modulus of elasticity of roll;

$l_t$  = inertia of roll.

10  
15  
20  
25  
30  
35  
40  
45  
50  
55  
60  
65  
70  
75  
80  
85  
90  
95  
100  
105  
110  
115  
120  
125  
130  
135  
140  
145  
150  
155  
160  
165  
170  
175  
180  
185  
190  
195  
200  
205  
210  
215  
220  
225  
230  
235  
240  
245  
250  
255  
260  
265  
270  
275  
280  
285  
290  
295  
300  
305  
310  
315  
320  
325  
330  
335  
340  
345  
350  
355  
360  
365  
370  
375  
380  
385  
390  
395  
400  
405  
410  
415  
420  
425  
430  
435  
440  
445  
450  
455  
460  
465  
470  
475  
480  
485  
490  
495  
500  
505  
510  
515  
520  
525  
530  
535  
540  
545  
550  
555  
560  
565  
570  
575  
580  
585  
590  
595  
600  
605  
610  
615  
620  
625  
630  
635  
640  
645  
650  
655  
660  
665  
670  
675  
680  
685  
690  
695  
700  
705  
710  
715  
720  
725  
730  
735  
740  
745  
750  
755  
760  
765  
770  
775  
780  
785  
790  
795  
800  
805  
810  
815  
820  
825  
830  
835  
840  
845  
850  
855  
860  
865  
870  
875  
880  
885  
890  
895  
900  
905  
910  
915  
920  
925  
930  
935  
940  
945  
950  
955  
960  
965  
970  
975  
980  
985  
990  
995

The sum of the loads that deflect the intermediate rolls in the whole set of rolls:

$$\Delta Q = \Sigma q_{ts} = \Sigma (((E_t \cdot l_t) / k) \cdot \delta_t)$$

wherein

$\Delta Q$  = change in overall load in the area of the set of rolls

The load that deflects the roll mantle expressed by means of component loads:

$$q_{ts} = G_{tv} / L + q_{ty} - q_{ta} + q_{ti}$$

wherein:

$G_{tv}$  = weight of roll mantle;

$q_{ty}$  = linear load in upper nip of roll;

$q_{ta}$  = linear load in lower nip of roll;

$q_{ti}$  = additional linear load arising from other factors in the area of the

20

roll mantle.

When it is taken into account that, in an intermediate nip between rolls, the upper and lower nip loads of adjacent rolls are of equal magnitude, the sum of the loads that deflect the intermediate rolls in the whole set of rolls is obtained as:

$$\Delta Q = \Sigma q_{ts} = \Sigma (G_{iv}/L) + q_{yy} - q_{aa} + \Sigma q_{ti}$$

wherein

$$q_{yy} = \text{linear load in the upper nip of the set of rolls}$$

$$q_{aa} = \text{linear load in the lower nip of the set of rolls}$$

When the deflections of the rolls are denoted equal and when they are substituted further, what is obtained is:

$$\delta = \delta_t$$

$$\Rightarrow \Delta Q = \delta/k \cdot \Sigma (E_t \cdot l_t)$$

$$\delta = \delta_t = \delta_o = (\Delta Q \cdot k) / \Sigma (E_t \cdot l_t)$$

When this is substituted further in the formula of the load that deflects a roll, what is obtained is:

$$q_{ts} = (E_t \cdot l_t) / \Sigma (E_t \cdot l_t) \cdot \Delta Q$$

Regarding the equilibrium of forces in a roll, the required support force per side is solved:

$$F_{tk} = 1/2 \cdot q_{ts} \cdot L + G_{tp}$$

$$\Rightarrow F_{tk} = 1/2 \cdot (E_t \cdot l_t) / \Sigma (E_t \cdot l_t) \cdot \Delta Q \cdot L + G_{tp}$$

wherein:

$$F_{tk} = \text{support force of roll per side;}$$

L = nip length;

$G_{tp}$  = weight of end parts of roll per side.

The computing of the support forces of the set of rolls in the calender, expressly of the entire set of rolls, is based on knowledge of the exact physical properties of the rolls, i.e., the conduct of all the rolls is known when deflecting loads of different magnitudes are applied to the rolls. It is a basis of the computing that the bearing support forces applied to each roll are determined so that the entire set of roll obtains an equally high calculatory deflection. Thus, by means of regulation of the support forces, it is possible to affect the ratio of the upper nip load and the lower nip load at an individual roll so that the sum of these loads, together with the respective mass of the roll, produces the same predetermined deflection in each individual roll.

The computing can be applied to a set of rolls of any kind whatsoever in a calender, which set of rolls is placed in a substantially vertical position, in which set of rolls the upper roll is an adjustable-crown roll and the lower roll likewise an adjustable-crown roll, the axial distribution of support forces of the upper and lower roll being adjustable, and in which set of rolls there are at least two intermediate rolls between the upper roll and the lower roll. Further, it is an important requirement that all the rolls in the set of rolls are supported so that their deflection lines are downwards curved when the nips are closed.

It is an important characteristic feature of the method, the arrangement, and the calender in accordance with the invention that, when computing the linear loads in the set of rolls, the physical properties of each intermediate roll that affect the deflection under load, such as bending rigidity, mass, shape, and material properties, are taken into account.

It is a further property that the bearing support forces of the intermediate rolls are

determined by means of computing so that the overall load applied to each intermediate roll subjects each intermediate roll substantially to a calculatory deflection such that the deflection forms of the contact faces of each roll, and the roll(s) in contact therewith in a nip, substantially correspond to one another.

5           The nip forces in a calender are regulated so that the difference between the nip forces of the uppermost nip and the lowest nip in the calender is determined to be at the desired level. This means, in fact, the regulation of the loading angle  $\alpha$  that was described in relation to FIGS. 2A, 2B and 2C.

10           To briefly summarize the foregoing, it can be stated further that it is an important feature of the invention that all the intermediate rolls in the set of rolls are supported to a greater extent than what is required by the pin forces (all mass outside the web). In such a case, the deflection lines of the rolls are downwards curved and substantially paraboloidal (parabolic). The support forces of each intermediate roll are regulated so that the deflection of the roll is adapted to the shapes of the other rolls in the set of rolls. Thus, the computing is carried out by means of the  
15           deflections. In this way, a group of equations is obtained in which the basic load between the rolls is determined so that the deflections of all the rolls are substantially equal. Thus, an equilibrium of forces is produced in the set of rolls. As the loading angle  $\alpha$ , it is possible to use any loading angle whatsoever, and the regulation of the loading angle  $\alpha$  is carried out by means of outside loading members through the lower roll and the upper roll. As a result, in the  
20           regulation of the deflection, the variable is the support force with which the roll is supported. Any errors produced by the mass of the areas outside the web in the distribution of linear load (and possibly other errors in the distribution of linear load) are corrected by means of the

adjustable-crown upper and lower rolls.

As shown in FIG. 6, the invention provides a novel possibility of taking care of the loading and the regulation of loading in the set of rolls in a multi-roll calender by the pair of rolls, which makes the system of regulation simpler and easier to carry into effect. As described above, in conventional supercalenders, generally rolls of two different types are employed as intermediate rolls and the rigidities of these two roll types are different. More particularly, as the intermediate rolls, hard-faced heatable rolls are used, on one hand, and soft-faced rolls are used, on the other hand, which soft-faced rolls can be conventional paper rolls or fiber rolls, which have been formed by fitting disks made of paper or of some other fibrous material onto the roll axle. As soft-faced rolls, today, ever increasing use is made of polymer-faced rolls, in which the roll frame consists of a tubular roll mantle. The rigidities of rolls of the same roll type are substantially equal to one another, but as stated above, the roll types differ from one another essentially with respect to rigidity and thus, also with respect to the deflection arising from the own mass.

In a conventional supercalender, the set of rolls comprises a stack of rolls placed in a substantially vertical or obliquely vertical position, wherein the rolls rest one on the other and the pin loads applied to the bearing housings of the rolls have been relieved hydraulically. The loading and profiling of the set of rolls is taken care of by means of variable-crown upper and lower rolls.

In the alternative mode of loading shown in FIG. 6, the set of rolls is treated as pairs of rolls 200, which consist of a more rigid roll 202 placed as the lower half in the pair of rolls 200 and a more flexible roll 201 placed as the upper half. Any deflection arising from the mass of the

upper roll 201 per se is higher than the deflection of the lower roll 202 in the pair. The pairs of rolls 200 in the set of rolls are substantially similar to one another, and they have equal, common deflections depending on the mass and rigidities of the rolls 201,202.

A force  $F_2$  is applied to the bearing housings of the upper and more flexible roll 201 in the pair of rolls 200, for example a hydraulic force, and by whose means, besides relief of the pin loads, any error in the distribution of linear load between the rolls may be compensated for. Such errors might arise from the different rigidities of the rolls 201,202. This can be illustrated by means of the formula:

$$2F_2 = m_{add2},$$

wherein:

$$F_2 = \text{force applied to the bearing housings of upper roll;}$$

$$m_{add2} = \text{mass of the bearing housings and the auxiliary devices attached to the bearing housing as well as the above error arising from different rigidities of the rolls.}$$

Thus, the upper roll 201 rests with its own weight  $m_2$  (from which the pin loads have been "cleaned") on the lower roll 202 and applies an even linear load  $m_2/L$  to the lower roll, wherein  $L$  is the axial length of the nip  $N$  between the rolls 201,202. On the other hand, a force  $F_1$  is applied to the bearing housings of the lower roll 202 in the pair of rolls 200, by means of which force the mass of both rolls 101,102 in the pair of rolls 200 as well as the pin loads of the lower roll 202 are supported. This can be illustrated by means of the formula:

$$2F_1 = m_1 + m_2 + m_{add1},$$

wherein:

$F_1$  = force applied to the bearing housings of the lower roll;  
 $m_1$  = mass of lower roll;  
 $m_2$  = mass of upper roll;  
 $m_{add1}$  = mass of the bearing housings of the lower roll and the auxiliary  
 5 devices attached to the bearing housings.

Thus, in an optimal situation, between the separate pairs of rolls 200, no forces arising  
 from the mass of the rolls are effective at all. In the nip N between the rolls 201,202 of the pair  
 of rolls 200, exclusively the linear load arising from the mass of the upper roll 201 is effective,  
 for example about from about 10 to about 20 kN/m. Owing to the differences between individual  
 10 rolls, the whole set of rolls must be treated as a whole, and the reliefs of each roll must be  
 optimized so that the cross-direction profile of linear load of the whole unit is as straight as  
 possible and the linear load arising from the mass of the rolls is as low as possible. In this  
 manner, a set of rolls with almost uniform loading is obtained, which set of rolls is, in most other  
 respects, loaded in the manner described above. For example, when a load of about 300 kN/m is  
 15 considered as the load level, in every second nip there is a difference in loading of about 5 per  
 cent only, as compared with the preceding or the following nip, i.e., with existing rolls, a  
 substantially even distribution of load is achieved.

Above, in connection with the description related to FIG. 6, for the sake of simplicity, it  
 has been assumed that the rigidities of the rolls 201,202 in the pair of rolls 200 are at a certain  
 20 ratio to one another and that the rigidities of the rolls belonging to the same type of rolls are  
 substantially equal to one another. However, as established above in relation to FIG. 5 clearly by  
 means of computing, there would not seem to exist any limitation arising from the mutual ratios



of the extents of specific deflections of the rolls. Thus any ratio of the rigidities of two rolls whatsoever can be compensated by means of computing so that the magnitudes of the linear loads in the whole set of rolls can be regulated so that they become substantially equal, with the exception of the deviation caused by the internal nips in calculatory pairs of rolls.

5           When conventional upper and lower rolls, for example rolls adjustable in zones, are used, a factor that limits uniform loading is the overall deflection of the intermediate rolls. This limitation could, however, be compensated for so that, if necessary, the lower roll is ground so that its diameter is smaller at the middle than at the ends (negative crown), so that the attainable maximal deflection of the roll adjustable in zones, together with the grinding shape, achieves the maximal possible deflection of the set of rolls. In this connection, it should be noted that, in a set of rolls of this type, the general direction of deflection of the rolls differs in such a way from the direction of deflection of so-called conventional supercalenders that the rolls are in a downwards curved position, instead of the upward curve form employed in a conventional supercalender.

10           In the regulation of loading carried out by the pair of rolls, in the set of rolls in a supercalender, compared with the illustration of FIG. 6, a difference is caused by the reversing nip in the calender, i.e., the nip in which the side of calendering of the web is changed. Generally, this reversing nip is the middle nip in the supercalender. This is illustrated in FIGS. 7A, 7B and 7C, in which three alternative modes of loading in a reversing nip are shown. In these figures, the pairs of rolls as shown in FIG. 6 and identical with one another are denoted by reference numeral 200. In a supercalender, the reversing nip is a nip that is formed between two soft-faced rolls 201, and in FIGS. 7A, 7B and 7C this reversing nip is denoted by  $N_e$ .

20           In the embodiment shown in FIG. 7A, this has been accomplished so that, in the "pair" of

rolls 200<sub>e</sub>, which is in this case formed by three rolls placed one above the other, the lower roll 202, which is a hard-faced and, for example, heatable roll, has a higher rigidity than the lower rolls in the other pairs of rolls 200. This is because the mass of the two upper rolls 201 rest on the lower roll 202.

5 In FIG. 7B, a corresponding construction has been accomplished so that the upper soft-faced roll 201<sub>e1</sub> in the reversing nip N<sub>e</sub> is arranged as a variable-crown roll. In such a construction, the deflection of the roll 201<sub>e1</sub> is corrected by means of the crown variation means situated in the interior of the roll, and the mass of the roll does not load the pair of rolls 200<sub>e1</sub> placed underneath by means of its weight.

10 In FIG. 7C, a corresponding construction has been accomplished so that the upper soft-faced roll 201<sub>e2</sub> in the reversing nip N<sub>e</sub> has been arranged as a roll with such a rigidity that its deflection is the same as the deflection of the whole pair of rolls 200,200<sub>e2</sub>. In such a case, the roll in the reversing nip does not cause any problem in the regulation of the loading.

15 With reference to FIG. 8, in the computing, in accordance with the invention, first the initial values of the rolls are defined, and a mathematical model corresponding to the set of rolls is formed on this basis. The mathematical model is formed in compliance with the number of rolls included in the set of rolls. The optimization computing formed for the set of rolls uses these data as the starting data. In the optimization computing that is to be carried out, the nip errors of the intermediate rolls are minimized, which errors have been defined as deviations from  
20 the nominal form. The resilience occurring between each nip and arising from the paper and from the coatings is illustrated by a base constant, which is computed across the nip length. The effects of the forces to be optimized on the linear load are determined in a response data base, in

which the unit response of the element of the nip of each intermediate roll is indicated in a desired number of examination points. The effects of invariable forces on the linear load are determined in a separate invariable-force data base, which takes into account divided masses, point masses, and nips with invariable load. Further, for the computing, the effects of the forces  
5 to be optimized on the restrictions and the effects of backup forces on the tension restrictions are determined. Thus, the optimization becomes a mathematical problem, in which the variables are limited and determined by groups of equations. As a result of the computing, optimal relief forces for intermediate rolls, optimal profiles of linear load and deflections of rolls are obtained.

After the computing operation, the optimized support forces of the intermediate rolls in the set of rolls of the calender are transferred to the support cylinders of intermediate rolls, as illustrated, for example, in FIG. 1. The optimized support forces of intermediate rolls are also transferred to the program of computing of the zone pressures of the variable-crown upper and lower rolls. The deflection values of the intermediate rolls in the set of rolls are used for controlling and regulating the variable-crown upper and lower rolls. From the deflection values of the intermediate rolls, by means of a separate computing program, the zone pressure corrections of the upper and the lower roll are determined, which corrections are, in each particular case, added to, or reduced from, each actual value of zone pressure. The distribution of linear load in the set of rolls is controlled in the method in accordance with the invention so that, by means of the user interface of the automation system, first the desired form of the  
20 distribution of linear load is determined. After this, the automation system and the included computing programs compute the above set values for the support pressures of the intermediate rolls and the zone pressures of the variable-crown upper and lower rolls. The method in

accordance with the invention also takes into account situations of change in the set of rolls arising from change of roll or from a new mode of running as well as any changes arising from such situations of change in the set-of-rolls data base, the parameter data bases and the computing. Likewise, in its roll and material data bases, the method covers and takes into account situations in which the diameters and/or material properties of chilled rolls and/or polymer rolls are changed.

With regard to the process conditions of calendering, it can be stated generally that they are determined by the capacities of the components that are used as rolls, as is also ordinary in calender technology. Further, restrictive factors in the process include the desired properties of paper, such as bulk (stiffness), smoothness/roughness, and gloss, in particular gloss of printing paper. As examples of process conditions, reference is made to U.S. Pat. Nos. 4,749,445 and 4,624,744 by S.D. Warren. A possible range of surface temperature of a heatable, so-called thermo roll is  $T_s$  = about 60°C to about 250 °C, depending on the running speed so that the surface temperature is lower at low running speeds and higher at high running speeds. This is because the time of effect of the nip is shorter and thus, the transfer of heat from the thermo roll to the web face is lower. The range of variation of linear load can be from about 20 kN/m to about 550 kN/m or even higher, again depending on the running speed and the properties of the variable-crown upper and lower rolls that produce the linear load in the supercalender.

Above, some preferred embodiments of the invention have been described, and it is obvious to a person skilled in the art that numerous modifications can be made to these embodiments within the scope of the inventive idea defined in the accompanying patent claims. As such, the examples provided above are not meant to be exclusive. Many other variations of

the present invention would be obvious to those skilled in the art, and are contemplated to be within the scope of the appended claims.

66E050" 205E0160